GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT INITIATION

August 9, 1967

Project Title: Polarization Agility Effects Study

Project No.: A-1034

Project Director: M. E. Wallace

Sponsor: Department of the Army, U. S. Army Missile Command

Effective 30 June 1967 Estimated to run until: 29 July 1968*

Type Agreement: Contract No. DA-AH01-67-C2322 Amount: $79,854.00

Reports: Monthly Progress Reports
Final Technical Report

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*13 month contract with last month for preparation and submission of final report

Assigned to Electronics Radar Branch Division

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REPORTS
No. A-103

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1/3/69

PROJECT TERMINATION

Date Dec. 31, 1968

PROJECT TITLE: Polarization Agility Effects Study (C)

PROJECT NO: A-1034

PROJECT DIRECTOR: G. W. Ewell

SPONSOR: Dept. of the Army, U. S. Army Missile Command

TERMINATION EFFECTIVE: 12-30-68

CHARGES SHOULD CLEAR ACCOUNTING BY: All acceptable charges have cleared.

Contract Actions Remaining: Submission of Classified Material Cert.

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A-1034

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

21 August 1967

U. S. Army Missile Command
Redstone Arsenal, Alabama 35804

Attention: AMSMI-RER

Reference: DA-AH01-67-C2322

Title: Polarization Agility Effects Study

Subject: Monthly Progress Report No. 1

Gentlemen:

A summary of progress for the period 1 July through 31 July is contained herein. Most of the work during this period was devoted to a literature search in subject areas pertinent to this program, such as polarization properties of targets and clutter, doppler radar techniques and measurements, and the mathematical modeling of radar targets. Some initial planning also was done with regard to the types of targets most compatible with both the experimental and theoretical aspects of the proposed study. Dipoles and collections of dipoles appear capable of providing useful information both theoretically and experimentally. Work has just begun on computer programs to predict the doppler return from such targets when they are illuminated with a signal whose polarization is varying.

A literature search has been made of the Georgia Tech "Bibliography of Radar Reflection Characteristics," the DDC Technical Abstract Bulletins, the Physics and Electrical Engineering sections of Science Abstracts, and the records of the University of Michigan Tri-Service Radar Symposia. Over two hundred documents of apparent interest were found. All the unclassified reports and many of the readily obtainable classified ones have been studied by Georgia Tech personnel. Copies of classified documents which were not available at Georgia Tech have been requested and will be examined as received. It appears that only a small part of the previous work is directly related to our problem while the remainder is primarily of background interest. The most interesting unclassified papers are listed below and discussed briefly. The titles of the pertinent classified papers studied to date also are given for reference.

1. Michigan University Research Institute Report 2591-1-H, "A Theoretical Method for the Calculation of the Radar Cross-Section of Aircraft and Missiles," (July 1959).

This report presents a three-step method for calculating the cross-section of practical targets: (1) resolve the target into a collection of simple shapes, (2) calculate the cross-section of each of these shapes, and (3) derive the total cross-section by properly summing these individual contributions. Some examples are given and compared with experimental data; agreement is generally within 6 dB for all aspect angles. While cross-section magnitude is not of fundamental interest in our study, the methods used in this investigation may be adaptable to the simulation problems in the present program.

2. NRL Memorandum Report 1474, "The Radar Target Scattering Matrix in Linearly and Circularly Polarized Components for Target Aspect Changes Around the Line of Sight," AD No. 453 174.

Radar target scattering equations are developed in matrix form for linearly and circularly polarized components. The effect on the target scattering matrix of rotating the target about the line of sight is presented for several geometrically simple targets. Since this would be equivalent to rotating the polarization with a fixed aspect, the results are of special interest in a study of polarization agility effects.

3. Gent, H., et al., "Polarization of Radar Echoes, Including Aircraft, Precipitation and Terrain," Proc. IEE (British) Vol. 110, No. 12, 2139-2148 (December 1963).

This paper presents results of measurements made on the echoing properties of various targets using circularly polarized radiation. When a single circular component was transmitted, the power reflected by aircraft was divided equally between the transmitted polarization and the orthogonal-sense circular polarization. The radar return using a plane-polarized transmitted signal consists of about ninety per cent of the transmitted polarization and ten per cent of the orthogonal polarization. Based on these two effects the authors concluded that the returns from aircraft consist mainly of simple single-bounce echoes from curved surfaces. This paper is of interest because of the data it gives on the polarization properties of aircraft type targets.

4. Technical Report No. RADC-TR-65-298, "Experimental and Analytical Investigation of Target Scattering Matrices," AD No. 477 070

Although the results obtained in this study are not directly applicable to the present problem, a very useful review of the matrix representation of target scattering is presented and utilized in the accompanying analysis. The scattering matrices of three targets are measured at 3 GHz and used in computer calculations of phase and cross-section for five different polarizations. Computed versus measured data is presented for one linear polarization.

5. Hudson, F. M., "Metal-Sprayed Fiberglass Radar Target Models," Radar Reflectivity Measurements Symposium, pp. 419-425 (April 1964), AD No. 601 364.

A method is presented for constructing large, complex-geometry targets at minimum expense. Savings up to 50% of the cost of all-metal construction is reported.

6. The Ohio State University Research Foundation Report 763-1, "The Significance of Phase in Microwave Measurement of Polarization Phenomena," AD No. 162 719.

Part B of this report deals with radar target polarization properties. A general equation is presented for the complex voltage induced in a rotating linearly-polarized radar receiving antenna. The author states that the polarization transforming properties of any target may be represented by a sphere and a "linear" target. Measurements are presented to validate this claim. Such a concept might be useful in our experimental program.

7. USASRDL TR 2148, "Polarization Sensitivities of Radar Targets (U)," Confidential Report. AD No. 319 985.

8. "Polarization Sensitivity as a Discriminant for Classes of Radar Targets (U)," Confidential Report. AD No. 332 022.

During the coming months the examination of classified reports will be continued. It is expected that some of the recent, classified work will be more applicable to the present program; a complete review of classified reports will be presented at a later date. More detailed plans will be formulated for the experimental portion of the study and work will proceed on the mathematical modeling of simple targets.

Very truly yours,

Marvin E. Wallace
Project Director

MEW:jan

Approved:

R. C. Johnson
Head, Radar Branch

A-1034

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

22 September 1967

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U. S. Army Missile Command
Redstone Arsenal, Alabama 35804

Attention: AMSMI-RER

Reference: DA-AH01-67-C2322

Title: Polarization Agility Effects Study

Subject: Monthly Progress Report No. 2

Gentlemen:

A summary of progress for the period 1 August through 31 August is contained herein. During this month major emphasis was placed on continuation of the literature search and planning of the experimental program. Computer programs were written to predict the return from combinations of dipoles illuminated by a polarization-agile radar. A trip to MICOM is planned by Marvin Wallace and J. D. Adams for the first week in September. The purpose of this trip is two-fold: (1) to obtain additional information on the problem which led to Georgia Tech's work on polarization agility, and (2) to discuss the measurement problems associated with the experimental portion of the program. Answers to several questions concerning the capabilities and operation of the experimental radar also are needed.

In the continuing literature survey and document study, numerous references were found to older documents not included in the sources initially searched. As a result, additional sources have been searched for pertinent work prior to 1957. A number of reports, both classified and unclassified, have been located. Those not available at Georgia Tech have been ordered from DDC; these reports will be reviewed as received.

Certification for DDC services on this project has just been completed and forms for classified and limited-distribution documents are now being processed. Study of available classified documents has continued. The most applicable documents are listed below for reference.

1. University of Michigan Report 2200(01)-1-T, "Radar Cross-sections of the F8U-1 and B-47 Aircraft (U)," Confidential Report. AD No. 370683L.

2. University of Michigan Report 2500-1-T, "Supplement to Radar Cross-sections of the F8U-1 and B-47 Aircraft (U)," Confidential Report. AD No. 370684L.

3. Report No. 1, Semi-Annual Report, "Reflection and Doppler Characteristics of Targets and Clutter (U)," Confidential Report. AD No. 358264.

4. Report No. 3, Semi-Annual Report, "Reflection and Doppler Characteristics of Targets and Clutter (U)," Confidential Report. AD No. 376793.

Simulation studies during the past month have consisted of computer calculations of the return from two mutually orthogonal, equal cross-section, dipoles with an arbritrary range and angular separation. Analysis of the computer output has just begun; results will be given for the cases of a 90 degree and a 180 degree phase-difference in the return from two dipoles along the same radial line-of-sight.

For 90 degrees phase-difference, the power received at the antenna terminals varies about 3 dB as the polarization-vector is rotated 180 degrees. The phase variation, θ, of the return is given by the relation: $\tan\theta = \tan^2\Phi$, where Φ is the orientation angle of the polarization-vector with respect to an arbitrary reference direction. Maximum rate of change of phase occurs at a polarization-vector orientation of 45 degrees to each of the dipoles.

For the case of 180 degree phase-difference, the received power at the antenna terminals oscillates between zero and the return due to a single dipole as the polarization is rotated. Zero values occur when the polarization-vector is oriented at a 45 degree angle to the dipoles. The phase of the return signal oscillates between zero and 180 degrees; reversals occur as the polarization-vector sweeps through the 45 degree positions.

Complete analysis of the computer return will yield the phase variation due to polarization rotation and the effect of this variation on apparent target velocity. The phase and magnitude variation of the return from each dipole may be used to calculate the relative pointing error (referenced to angular separation) as a function of polarization.

It is anticipated that the Ampex FR-600 magnetic tape recorder available at Redstone Arsenal will be used for direct recording of all experimental data. A handbook on this recorder has been borrowed from the local Ampex representative. It is essential that the complete Doppler spectrum be recorded throughout each field test. Since this spectrum may contain DC components, it is probable that FM recording must be used. However, during the initial tests, a simultaneous AM record of the Doppler data will be taken to determine whether an AM recording would be satisfactory.

The frequency limitation on the FR-600 for FM channels is approximately 20 kHz. Since any spurious Doppler components will be related to the rate at which polarization is varied, components at very high frequencies may exist in the Doppler spectrum, particularly if the polarization is changed on a pulse-to-pulse basis. Consequently, it may be necessary to reduce the present p.r.f. somewhat so that all Doppler components will be faithfully reproduced.

Two methods are being considered for retrieving the Doppler spectrum from the recorded data. The first method consists of using a digital computer to perform a Fourier integration on the data and yield the frequency spectrum. This type of analysis will be much facilitated if analog-to-digital conversion equipment is available. The second method involves the use of a narrowband, tunable filter to separate the individual Doppler components. Although the first method of analysis will be very time consuming without analog-to-digital equipment, it is planned that both methods will be used initially and their results compared.

Other signals besides the Doppler output also will be measured. For example, the polarization state for each return pulse must be recorded. This can be accomplished most conveniently by using a trigger pulse which occurs in the programmer once each cycle during automatic polarization scanning. If the mode of the programmer is noted on a voice channel, it is relatively simple to reconstruct the polarization for each pulse by counting the number of return pulses since the last trigger pulse from the programmer. Each return pulse will be stretched to approximately half the interpulse period; a zero level then will be available between pulses to facilitate pulse counting. In addition to the polarization state, a record also will be made of the amplitude of each return pulse, the position of the conical scanner for each transmitted pulse, and, whenever possible, the error signals being generated within the radar.

The experimental radar presents some problems in recording the desired signals. The normal Doppler output is effectively filtered by a narrowband filter; as a consequence, any high-frequency components will not appear at this output. Therefore the Doppler data must be recorded ahead of the filter. This may require the use of an external mixer and amplifier as well as some modification to the radar. A similar problem exists in error signal recording since these signals also are filtered.

The schedule of the planned experimental program is approximately as follows. Shortly after the delivery of the polarization-agile antennas, a familiarization visit will be made to the radar field site by those Georgia Tech personnel who will be involved with the experimental measurements. It is hoped that this trip can be made during the month of October. Following the familiarization trip, any required modification equipment will be completed. A second trip then will be made by the field crew; the radar will be calibrated and prepared for tests with actual targets. A polarization insensitive target such as a flat plate, a sphere, or a parabolic reflector will be employed for calibration purposes.

As a part of the calibration procedure, it is necessary to verify that any effect of polarization agility on the radar return is due to the targets themselves and not the equipment. To facilitate this verification the radar will be compensated by adding a phase shifter to the receiver. This phase shifter will be electronically programmed to compensate phase shifts introduced by the polarization-agile antennas when the polarization direction is changed.

As soon as possible after calibration of the equipment, suitable targets will be selected for the initial tests. Two general types of targets are anticipated. One type will consist of simple geometrical shapes such as spheres, cylinders, or corner reflectors and combinations of these which tend to simulate real targets of interest. The second type of target will include such things as airplanes, helicopters, tanks and other ground vehicles. Initial measurements will be made on stationary targets; tests on moving targets are planned for later in the program.

Future work will include additional planning of the experimental program and mathematical simulation of targets. The computer simulation studies will involve not only dipoles but also such targets as cylinders, spheres, corner reflectors, and combinations of these. The study of documents pertaining to the program also will be continued.

Respectfully submitted,

Marvin E. Wallace
Project Director and
Technical Coordinator

MEW:na

cc: R. C. Johnson
Head, Radar Branch

A-1034

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

31 October 1967

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U. S. Army Missile Command
Redstone Arsenal, Alabama 35804

Attention: AMSMI-RER

Reference: DA-AH01-67-C2322

Title: Polarization Agility Effects Study

Subject: Monthly Progress Report No. 3

Gentlemen:

A summary of the work performed during the period 1 September through 30 September is contained herein. As in the two previous months, effort has been divided among three major areas: (1) review of published reports, (2) preparation for the experimental portion of the program, and (3) mathematical simulation. In addition, a trip was made to MICOM by M. E. Wallace and J. D. Adams to discuss the project and secure additional information.

Requested reports are continually being received and studied. Several of those reviewed during the past month have proved highly interesting; they are listed below with a discussion of the unclassified ones.

1. Royal Radar Establishment Technical Note No. 585, "Measurements of Glint at Short Range (U)." Secret Report. AD 106305.

2. Ohio State University Research Foundation Report 389-11, "Effects of Type of Polarization on Echo Characteristics (U)." AD 492703.
   The variation in echoing area as a function of the direction of linear polarization is presented for a 1/20th scale F-80 aircraft. Radar return patterns are presented for polarization vectors inclined to the horizontal at 0, 15, 30, 45, 60, and 75 degrees. These patterns cover a range of aspects 40 degrees to either side of nose-on in a horizontal plane. The high peaks and deep nulls observed are indicative of a small number of individual scatterers whose relative phase is varying.

3. Hughes Aircraft Company Technical Memorandum No. 23, "Angular Scintillation of Radar Targets (U)." ATI 82175.

   This report derives a statistical relationship for the wander of the apparent radar position of a target composed of a large number of point reflectors. For the case of a target with symmetry about two orthogonal axes, the probability that the apparent radar center lies outside the target is 0.20. For a long,narrow, uniformly distributed target, the probability of the apparent radar center lying off the target is 0.27.

4. M.I.T. Meteor Report No. 77, "Errors in Angle Radar Systems Caused By Complex Targets (U)." ATI 194475.

   An analysis is made of the error introduced into various radar systems due to wander of the apparent radar center. This error is shown to be independent of the type of radar system at ranges for which the illumination is constant across the aperture of the receiving system. At shorter ranges, lobe-comparison systems become slightly less accurate than phase-comparison systems.

   Wander data at X-band are presented for the B-29, C-46, B-26, AT-6 and AT-11 aircraft. The aircraft were optically tracked to obtain true target position. Spectra of the wander data show that for large aircraft, frequency components above 40 cps can exist. Maximum spectra components were observed near zero frequency; their average amplitude varied between 2.5 and 8 feet for the different targets.

   This paper presents a strong justification for representing real targets by a two-scatterer model. Using this model and assuming a ratio of 0.8 for the echo area of the two scatterers, values of wander consistent with experimental data were computed.

Preliminary calculations have been performed to better define some of the problems associated with measurements on stationary model targets. Assuming a 3 dB beamwidth of two degrees and a pulse length of 0.25 microseconds, an order-of-magnitude estimate of the clutter cross-section for a grassy field at 2000 feet is about one square foot. By comparison, a sphere two feet in diameter has a cross-section about three times this and a 36 gauge wire 10 feet long has a maximum (longitudinal polarization) cross-section of about 100 square feet. The estimated value of clutter cross-section indicates that the return from clutter at 2000 feet should be well within the radar's detectability range. This suggests that it will be necessary to make tests on clutter alone in order to determine the contribution of clutter returns to the total received Doppler signal. During tests on targets of fairly large cross-section, it may be possible to reduce receiver gain and prevent the clutter return from reaching the phase-sensitive detector. If the clutter cross-sections observed in practice are significantly larger than one square foot, the feasibility of using moderate sized stationary targets for measuring the effect of polarization variation on the Doppler return is doubtful.

Some consideration has also been given to the multipath problem for fixed targets. For an antenna height of 10 feet, the reflected ray hitting the target will be down by at least 10 dB for target elevations greater than 35 feet. Since range facilities already exist at MICOM for elevating targets above 50 feet, multipath effects should not be a severe problem. It may be necessary to cover the poles or other wooden target supports with microwave absorber material to prevent their return from confusing the return from the actual targets.

One of the principal complications in measuring the effect of polarization variation on the Doppler return from moving targets is in controlling the target motion. For the case of model targets, it is difficult to devise any practical means for moving them in the field. For vehicular and aircraft targets, one major problem is repeating the target velocity with respect to the radar.

A computer program has been written to calculate the phase variation of the return from a fixed target consisting of a sphere and a thin wire whose cross-section is one-half the cross-section of the sphere. This combination was chosen as being a practical polarization dependent model for initial consideration. The apparent radar center of this target has also been calculated as a function of polarization for various phase differences between the returns from the two scatterers. An existing program has been adapted to perform a Fourier analysis on the calculated data. This program also can be used with analog-to-digital conversion equipment to perform automated analysis of experimental data.

On 7 September a trip was made to MICOM by Marvin Wallace and J. D. Adams. The purposes of this trip were (1) to discuss the measurement problems and (2) to obtain additional information on the operational requirements which led to this contract. At a meeting attended by the above and Messers. Gene Wood, Ed Holliday, Bill Pittman, and Carl Cash of MICOM, these operational requirements were discussed and information obtained which should aid in planning meaningful tests. Measurement problems and the experimental radar were subsequently discussed at length with Mr. Ed Holliday. As a result of this discussion and study of material furnished by Mr. Holliday, it has become apparent that modifications to the present radar will be required to permit recording of the complete Doppler output. These required modifications are primarily due to bandwidth limitations in the existing receiver. Present plans are to connect an external phase-sensitive detector to the output of the existing 60 MHz IF amplifier and obtain the Doppler spectra without further mixing.

On 29 September Mr. Carl Cash of MICOM visited Georgia Tech to discuss plans for the experimental tests at Redstone Arsenal. A tentative schedule for test facilities, vehicular and aircraft targets, and support personnel was formulated to enable Mr. Cash to arrange their availability. Georgia Tech will be advised of specific dates when this schedule becomes fixed.

During the next month primary effort will be devoted to continuing the theoretical portion of the program. Additional computer analyses will be performed and simulation studies involving combinations of simple targets will be pursued. Preliminary design of the additional instrumentation required in tests utilizing the MICOM experimental radar will be completed.

Respectfully submitted,

Marvin E. Wallace
Project Director and
Technical Coordinator

MEW:na

cc: R. C. Johnson
Head, Radar Branch

A-1034

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

30 November 1967

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U. S. Army Missile Command
Redstone Arsenal, Alabama 35804

Attention: AMSMI-RER

Reference: DA-AH01-67-C2322

Title: Polarization Agility Effects Study

Subject: Monthly Progress Report No. 4

Gentlemen:

A summary of the work performed during the period 1 October through 31 October is contained herein. During this period, major effort has been devoted to mathematical analysis of some simple targets. Work has continued on the planning of experiments and the design of instrumentation for the proposed field operations.

Monthly Progress Report No. 3 discussed the phase variation of the return from a fixed target composed of a sphere and a thin wire when illuminated by a signal whose plane of linear polarization was varied. Since this phase variation would appear as spurious doppler frequencies, an analysis has been made to determine the relative magnitude of these components in the radar return from such a target. A PRR of 10,000 pps and polarization changes of both $5\frac{1}{2}^\circ$ and $22\frac{1}{2}^\circ$ between each transmitted pulse were assumed for this analysis. A PRR of 10,000 pps was chosen because of the bandwidth limitation of the data recording equipment which will be used for actual field measurements; this limitation was discussed in Monthly Progress Report No. 2. However, the results of this analysis can be translated to any other PRR by multiplying the spurious doppler frequencies calculated for this particular case by a constant scale factor.

For polarization changes of about $5\frac{1}{2}^{\circ}$ per transmitted pulse and a total polarization rotation of 180°, the lowest significant doppler frequency due to polarization rotation occurs at 312.5 Hz. Although analysis of this case is not complete, significant frequency components are predicted through the 16th harmonic of 312.5 Hz for some assumed values of relative phase between returns from the sphere and the wire. This harmonic corresponds to the Nyquist frequency of 5 KHz which is the highest frequency susceptible to analysis for a PRR of 10,000 pps.

For polarization changes of $22\frac{1}{2}^{\circ}$ per transmitted pulse and a total polarization rotation of 180°, the lowest significant doppler frequency component due to polarization rotation occurs at 1.25 KHz. Again, there are significant frequency components up to the Nyquist frequency of 5 KHz, which in this case occurs at the fourth harmonic of 1.25 KHz. Although the relative power level of the spurious doppler frequencies is a function of the assumed separation between the target components, the lowest frequency component (1.25 KHz) is the largest for all values of separation. The second harmonic (2.5 KHz) is 17 to 50 dB down, the third harmonic is 10 to 30 dB down and the fourth harmonic is 2 to 4 dB down from the level of the 1.25 KHz component.

Doppler components have been calculated for the sphere-plus-wire target moving with a constant velocity of about 84 mph with polarization changes of $22\frac{1}{2}^{\circ}$ per transmitted pulse and a total polarization variation of 180°. The true doppler component due to the target's velocity occurs at 2.5 KHz which is also the frequency of the lowest amplitude spurious doppler frequency in the above analysis of polarization-rotation only. This permits some comparison between the amplitudes of the true doppler frequency and the spurious components due to polarization variation. The true velocity component due to target motion is from 14 to 28 dB larger than the spurious components due to polarization rotation.

Triangular corner reflectors of various cross-section are available at Georgia Tech for use in the proposed field operation; consequently, targets for the equipment check-out and calibration tests should present no difficulty.

Work is continuing on the design of equipment for the required radar modification. Several types of phase detectors are being considered for this application, and samples of some commercial phase detectors have been obtained for study and evaluation. Power supplies and other long lead-time items of equipment which will be required for the radar modification were received this month.

During the coming months, the mathematical simulation of targets will continue. The existing MICOM pulse-doppler radar will be suitably modified to permit measurement of the doppler return from fixed and moving targets of interest and a comprehensive field measurements program will be begun. The procurement and study of documents pertaining to the program will continue.

Respectfully submitted,

Marvin E. Wallace
Project Director and
Technical Coordinator

MEW:na

cc: R. C. Johnson
Head, Radar Branch

A-1034

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

21 December 1967

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U. S. Army Missile Command
Redstone Arsenal, Alabama 35804

Attention: AMSMI-RER

Reference: DA-AH01-67-C2322

Title: Polarization Agility Effects Study

Subject: Monthly Progress Report No. 5

Gentlemen:

A summary of the work performed during the period 1 November through 30 November is contained herein. During this period, work has continued on the mathematical analysis of the radar return from simple targets, some additional circuits required to instrument the radar have been constructed, and some pertinent reports have been received.

The most pertinent reports received during the past month are listed below, along with a brief discussion of the unclassified report. The pertinent classified reports reviewed during this project will be discussed in a later progress letter.

1. Interim Technical Report No. 1, "Hypervelocity Interceptor Radar Feasibility Study (U)," AD No. 489727L.
   A brief discussion is presented of the pointing error of a radar tracking a target composed of a "cone-sphere." Major parameters are as follows: assumed cross-section ratios of 0.5 and 0.9, range-to-target of 2500 ft., wavelength of 3 cm., and a phase difference between target elements of 180°. For the case of 0.5 cross-section ratio, a maximum pointing error of 12 ft. is obtained. When the cross-section ratio is increased to 0.9, the maximum pointing error becomes 76 ft. These numbers apply only for the assumed range of 2500 ft.

2. Ohio State University Research Foundation Rept. 777-1, "Location of Scatters on a Complex Target By Means of a Tracking Radar System (U)," Confidential Report. AD No. 162696.

3. Ohio State University Research Foundation Rept. 601-28, "The Effects of Polarization on the Echo Area and Scintillation of the F-86 Aircraft at Several Frequencies (U)," Confidential Report. AD No. 150184.

The computer analysis of the Doppler return from radar targets discussed in Monthly Progress Report No. 4 has continued. Additional results have been obtained for the sphere-plus-wire target with a true Doppler frequency of 2.5 KHz. For the assumed radar frequency of 10 GHz, this corresponds to a radial velocity of about 84 mph. As stated in the previous progress report, for a target with zero velocity, polarization changes of about $5\frac{1}{2}^{\circ}$ per pulse generate spurious Doppler components with significant relative magnitude through the sixteenth harmonic. However, for an assumed target velocity of 84 mph, the true Doppler component is greater than the strongest spurious by 10 to 20 dB, depending upon the assumed separation between the sphere and the wire. If these results are typical for a range of target velocities and polarization step sizes, it should be possible to eliminate the effects of spurious frequency components due to polarization rotation by establishing a threshold at the output of the Doppler filter. In order to investigate this possibility, analysis of the return from the wire-plus-sphere target has been initiated for the cases of target motion without polarization agility, polarization agility with a motionless target, and polarization agility with a moving target. These returns will be analyzed for a wide range of target velocities, polarization step sizes and separation of target components. The results will be analyzed to determine if a suitable threshold would eliminate the spurious frequency components due to polarization rotation and still allow target detection without significant degradation of radar performance.

The design of a wide-band phase detector for use in the experimental portion of the program has been selected, and breadboard models of the phase detector and the necessary circuits to connect it to the tape recorder have been constructed. Considerable time and effort have been spent to insure that these circuits will function reliably and stably when subjected to the climatic conditions under which they will be operated. As soon as feasible, these circuits will be attached to the radar and their performance will be evaluated.

Some of the components necessary for increasing the range of the Pulses/Position function of the Polarization Programmer have not been received, but the required printed circuit cards have been fabricated and the modification will be performed as soon as the remainder of the components are in hand.

During the coming months, the mathematical simulation of radar targets will continue, the additional instrumentation will be interfaced with the radar, and the program of field measurements will begin. The procurement and study of documents pertaining to this program also will continue.

Respectfully submitted,

George W. Ewell
Project Director

GWE:na

Approved:

Marvin E. Wallace
Technical Coordinator

cc: R. C. Johnson
Head, Radar Branch

A-1034

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION

225 North Avenue, Northwest · Atlanta, Georgia 30332

29 January 1968

U. S. Army Missile Command
Redstone Arsenal, Alabama 35804

Attention: AMSMI-RER

Reference: DA-AH01-67-C2322

Title: Polarization Agility Effects Study

Subject: Monthly Progress Report No. 6

Gentlemen:

A summary of progress for the period 1 December through 31 December is contained herein. During this period work has continued on the mathematical analysis of the radar return from simple targets and on preparations for the forthcoming field operations.

On 13 and 14 December, G. W. Ewell, M. E. Wallace, and R. C. Johnson traveled to Redstone Arsenal to discuss plans and co-ordination of the field tests to be conducted by MICOM and by Georgia Tech. The problem of providing an indication of the plane of transmitted polarization was considered and it developed that a continuous indication of polarization is required for compatibility with the data reduction methods to be used by MICOM. Georgia Tech is investigating modifications to the Polarization Programmer which will provide the required polarization indication.

The Polarization Programmer has been modified to increase the range of the Pulses/Position function. The Programmer was originally constructed to permit the selection of 1 to 99 transmitted pulses between polarization changes; it has been modified to provide the following ranges: 1 to 99 pulses in one-pulse increments, 10 to 990 pulses in 10-pulse increments, and 100 to 9900 pulses in 100-pulse increments. The new modes of operation are selected by an additional Pulses/Position switch which has been added to the front panel of the Polarization Programmer.

Georgia Tech personnel visited the MICOM field site on 14 December to verify the compatibility of the outputs of the radar with additional instrumentation being constructed by Georgia Tech for use during the field tests. Although the radar was not fully operational, a number of the required measurements were made. All other necessary measurements were performed by MICOM personnel shortly after the visit. Several test tapes were run on the MICOM Ampex FR-600 tape recorder to insure its compatibility with the Honeywell 7600 tape recorder at Georgia Tech. The only difficulty encountered was that the voice edge-track is on opposite edges of the tape in the two machines. In order to use both voice and data tracks, the tapes must be played back in the reverse direction through the Honeywell 7600.

The additional digital latching X-band phase shifter which is necessary to compensate for the phase variations introduced by the polarization-agile antennas has been ordered from Scientific-Atlanta and is scheduled for delivery the latter part of January. The design of the necessary circuitry to operate this phase shifter has begun, and the necessary power supplies have been received.

During the coming months, the mathematical simulation of radar targets and the procurement and study of documents pertaining to this program will continue. The measurements program with the radar will be initiated and the resulting test data will be analyzed.

Respectfully submitted,

George W. Ewell
Project Director

GWE:na

Approved:

Marvin E. Wallace
Technical Coordinator

cc: R. C. Johnson, Head, Radar Branch

A-1034

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION

225 North Avenue, Northwest · Atlanta, Georgia 30332

21 February 1968

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U. S. Army Missile Command
Redstone Arsenal, Alabama 35804

Attention: AMSMI-RER

Reference: DA-AH01-67-C2322

Title: Polarization Agility Effects Study

Subject: Monthly Progress Report No. 7

Gentlemen:

A summary of progress for the period 1 January through 31 January is contained herein. During this period work has continued on the mathematical simulation of the radar return from simple targets and on preparations for collecting and analyzing data from the proposed field operation.

A continuous indication of the plane of linear polarization of the antennas is required in order to be compatible with the data reduction methods proposed by MICOM; the problem of obtaining a suitable indication of polarization was discussed briefly in Progress Report No. 7. No appropriate output is directly available from the antennas or the Polarization Programmer. Consequently, a modification to the Polarization Programmer has been designed, and the necessary printed circuit cards have been fabricated to provide an output which is directly related to the plane of transmitted and received polarization. This modification, which is basically a digital-to-analog converter, has an output voltage range of approximately -0.5 volts to +2.3 volts. There are 32 possible voltage levels within this range, corresponding to the 32 possible polarizations. This modification has been thoroughly tested and will be installed in the Polarization Programmer as soon as possible.

The compensating X-band phase shifter has been received. This phase shifter will be placed in the transmitter line; it will be located inside the box which is mounted above the transmitting antenna. Fabrication of the necessary waveguide components and mounting hardware to install the phase shifter has begun and the additional circuitry and cables required to operate it have been constructed and tested. As soon as the waveguide and mounting hardware are completed, the phase shifter will be installed.

Additional FM filters have been installed in the Honeywell 7600 tape recorder at Georgia Tech to increase its playback capability and facilitate the reduction of recorded data. By recording data in the FM mode and playing it back at a slower tape speed, an effective expansion of the time scale may be accomplished without distortion of amplitude information. This will permit the use of such devices as optical-writing chart recorders (visicorders), whose bandwidth is normally too narrow to reproduce accurately the type of data to be recorded.

One important phase of this project has been a continuing search of available literature for information useful in investigating the effects of polarization agility on radar range and velocity measurement. Several unclassified papers have been reviewed in earlier progress reports. A review of all pertinent classified reports to date is attached as a classified appendix to this report.

On 11 January, G. W. Ewell visited Redstone Arsenal to investigate any interface problems which might exist between the new Georgia Tech instrumentation and the MICOM radar. The wide-band phase detector and associated circuitry were operated with the MICOM radar and all circuits functioned normally.

During the coming months, the planned field measurement program will be performed. The recording and analysis of the Doppler return from real targets will begin as soon as the compensating phase shifter is installed. The mathematical analysis of the return from simple targets and the procurement and study of documents pertaining to this project will continue.

Respectfully submitted,

George W. Ewell
Project Director

GWE:na

Approved:

Marvin E. Wallace, Technical Coordinator

cc: R. C. Johnson, Head, Radar Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
225 North Avenue, Northwest · Atlanta, Georgia 30332

15 March 1968

A-1034

U. S. Army Missile Command
Redstone Arsenal, Alabama 35804

Attention: AMSMI-RER

Reference: DA-AH01-67-C2322

Title: Polarization Agility Effects Study

Subject: Monthly Progress Report No. 8

Gentlemen:

A summary of progress for the period 1 February through 29 February is contained herein. During this period, work has continued on the mathematical simulation and analysis of the radar return from simple targets. Some modifications have been made to the MICOM radar, and the experimental measurements program has begun.

On February 1, G. W. Ewell visited Redstone Arsenal to prepare for the field operations. Modification of the Polarization Programmer to provide a direct indication of the polarization of the antennas was discussed in Monthly Progress Report No. 7. Mr. Ewell installed equipment to implement this modification and thoroughly checked the Polarization Programmer to insure proper operation. Poor weather conditions and a faulty 400 Hz generator at the field site prevented operation of the radar during this trip.

On February 27 and 28, G. W. Ewell visited Redstone Arsenal to conduct preliminary field tests. As mentioned in previous reports, an additional phase shifter is required to compensate for phase variations introduced by the polarization-agile antennas. Mr. Ewell installed this digital latching X-band phase shifter in the input line of the transmitter antenna. He also installed and checked out the additional circuitry and power supplies necessary to operate this compensating phase shifter. The radar then was operated as a polarization-agile radar and the Doppler return from several targets was observed. The targets observed included a triangular corner reflector mounted on a wooden tower and an M-48 tank parked on a hillside among light ground clutter. Doppler information from these targets was recorded on magnetic tape for a wide range of polarization step sizes and for different numbers of transmitted pulses between polarization changes. Poor weather conditions and difficulties with the conical scan motor prevented as complete a field operation as was desired.

The magnetic tapes containing the information recorded during these field tests were brought back to Georgia Tech where several alternate methods are available to analyze field-recorded data. The tapes may be played back at a reduced tape speed and the data recorded on a wideband, light-writing, strip chart recorder. Although some information can be derived from visual examination of this record, the information normally is manually transferred to punched cards and the return analyzed on a digital computer. Another general analysis technique involves the use of a low frequency spectrum analyzer and/or a wave analyzer--a tunable narrow band filter with a visual output of signal amplitude. The frequency translation available when playing back FM recorded data can be used to shift the Doppler frequency components of interest so they fall within the operating range of these instruments. This technique is quicker and less expensive than digital methods, but digital analysis is more accurate and versatile. The data recorded during the preliminary field tests have been analyzed by both methods as a check on the results.

Some of the recorded data on stationary targets do not exhibit the expected Doppler components associated with polarization variations. Several explanations are possible for the observed Doppler spectrum of the return. The two most probable are a malfunction of some component of the radar or the presence of additional strong scatterers in the radar cells of resolution which contained the test targets. Special tests will be conducted during the next field operation to determine the cause of the observed Doppler spectrum; these will include the necessary procedures to verify proper operation of the radar.

An important portion of this project has been the theoretical analysis of the radar return from combinations of simple targets; this analysis should give an indication of the general behavior of the return from real targets when illuminated by a polarization-agile radar signal. A special technical report describing this work is being prepared and will be issued shortly.

During the coming months, theoretical analyses of the return from simulated targets will emphasize polarization rotation rates and polarization sequences which experimental measurements show to be of most interest. The program of field operations and the procurement and study of documents pertaining to this project will continue. An analytical study of the effects of polarization agility on radar range measurement accuracy also will be conducted.

Respectfully submitted,

George W. Ewell
Project Director

GWE:na

Approved:

Marvin E. Wallace
Technical Coordinator

cc: R. C. Johnson
Head, Radar Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION

225 North Avenue, Northwest · Atlanta, Georgia 30332

18 April 1968

A-1034

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U. S. Army Missile Command
Redstone Arsenal, Alabama 35804

Attention: AMSMI-RER

Reference: DA-AH01-67-C-2322

Title: Polarization Agility Effects Study

Subject: Monthly Progress Report No. 9

Gentlemen:

A summary of progress for the period 1 March through 31 March is contained herein. During this period, tests were performed to verify proper operation of the polarization-agile radar. Some of the problems uncovered by these tests were corrected, and an investigation of the effects of polarization agility on range measurement accuracy was begun.

The investigation of the effects of polarization agility on range measurement accuracy has been initiated with a search of the available literature. There appears to be little directly applicable information available, but reported techniques which have been employed to calculate the shape of returned pulses from target models may prove useful.

Monthly Progress Report No. 8 mentioned the unexpected variations which were observed in the Doppler return from some real targets when viewed with the MICOM polarization-agile radar. This effect was investigated, and it was determined that an X-band phase shifter which was installed to compensate for phase variations introduced by the polarization-agile antennas was improperly wired by the manufacturer. To save time the problem was corrected by modifying the circuitry which supplied triggers to this phase shifter rather than by having the manufacturer rework the phase shifter. Proper operation of the compensating phase shifter then was verified.

Tests were performed to determine if the polarization-agile antennas were functioning properly. Preliminary tests consisted of measurements of the radar return from targets having known polarization properties. Since the observed return was not as expected, tracking of the transmitter and receiver antennas was checked using a rotatable horn to transmit or receive a known linear polarization. It was found that poor solder joints on printed circuit cards and ground loops in the compensating phase shifter circuitry were preventing proper operation of the antennas. These problems were corrected in the field and antenna tracking within six degrees was measured at 9.89 GHz. Additional cables are being fabricated which will completely restore the polarization tracking accuracy of the antennas.

Since neither the antennas nor the compensating phase shifter were working properly during the field tests conducted thus far, the measured data have not yielded useful information on the effects of polarization agility on Doppler returns. However, processing of this data did reveal that the computer program which had been written to perform Fourier analyses of theoretical returns from model targets was extremely time consuming when used to analyze the large amounts of data obtained during a field operation. Therefore, the computer program was rewritten to reduce the computation time by 50 to 70%, depending upon the length of the data sample.

A preliminary draft of a technical report describing the theoretical analysis of the effects of polarization agility on the Doppler return from combinations of simple targets has been prepared, and a copy has been transmitted to MICOM for inspection and comment.

During the next month, the defective circuitry in the antennas will be completely replaced and proper operation will be verified. Additional field data then will be recorded and analyzed, and the experimental and analytical results compared. Additional theoretical analysis will be performed for any cases which are demonstrated by these comparisons to be of particular interest. The study of the effects of polarization agility on range measurement accuracy will be pursued, and the procurement and study of documents pertaining to this project will continue.

Respectfully submitted,

George W. Ewell
Project Director

GWE:jan

Approved:

Marvin E. Wallace
Technical Coordinator

cc: R. C. Johnson
Head, Radar Branch

GEORGIA INSTITUTE OF TECHNOLOGY
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15 May 1968

U. S. Army Missile Command
Redstone Arsenal, Alabama 35804

a 1034

Attention: AMSMI-RER

Reference: DA-AH01-67-C-2322

Title: Polarization Agility Effects Study

Subject: Monthly Progress Report No. 10

Gentlemen:

A summary of progress for the period from 1 April through 30 April is contained herein. During this period, additional analytical investigations of the effects of polarization agility on the Doppler return from model targets were performed, polarization tracking of the two antennas was verified, a field operation was conducted, and the recorded field data were analyzed. The results of this analysis showed some effects of polarization agility on the Doppler return from stationary artificial targets and from moving and stationary civilian vehicles.

Previous analytical work under this program predicted the Doppler return from a model target consisting of one polarization sensitive and one polarization insensitive scatterer. The polarization insensitive target component was assumed to have a cross section twice as large as the maximum cross section of the polarization sensitive target component, and the results were analyzed for several different polarization rotation schemes. In order to determine the effect of cross section ratio on the Doppler return, additional analyses were performed for equal cross sections and for an assumed maximum cross section of the polarization sensitive component equal to twice that of the polarization insensitive component. The results of these new analyses were similar to those previously reported; a Doppler frequency component due to target velocity is observed along with components related to the polarization rotation rate. As in previous cases, the Doppler component corresponding to the assumed target velocity is considerably larger than any spurious components due to polarization rotation. As might be expected, the amplitudes of the components due to polarization rotation increase as the relative cross section of the polarization sensitive target component increases. However, the rate of change of the amplitude is less than that of the relative cross section. Even for the most severe case considered, where the maximum cross section of the polarization sensitive component was twice that of the polarization insensitive component, the Doppler component associated with target motion was significantly larger than any component due to polarization rotation.

The tracking problems of the polarization-agile antennas have been discussed in previous Monthly Progress Reports. These problems have been corrected by fabricating and installing some new interconnecting cables to eliminate ground loops in the circuits which drive the compensating phase shifter. The polarization tracking of the antennas, as measured at 9.89 GHz, has been restored to the accuracy measured at the time of delivery.

To verify that the compensating phase shifter was operating properly and that no spurious Doppler components were generated by the antennas or data processing equipment, the Doppler return from a triangular corner reflector was recorded and analyzed. Operation of the phase detector was checked by the use of a mechanical phase shifter between the output of the receiver antenna and the receiver mixer. A corner reflector was illuminated with a signal of constant polarization and the relative phase of the return from the reflector was changed by varying the phase shifter. The phase detector output as a function of the manual phase shifter setting was observed, thus verifying proper operation of the phase detector.

After proper operation of the radar and the data collection and data recording equipment was established, the Doppler return from a civilian vehicle was recorded for a variety of polarization rotation sequences. Data were taken for the vehicle both stationary and moving. The data tapes then were returned to Georgia Tech and analyzed. Many analyses were performed for each target situation of interest using a spectrum analyzer to operate an X-Y recorder.

The spectra of the Doppler return from a civilian vehicle illuminated by alternating orthogonal polarizations with ten transmitted pulses per polarization position are presented in Figures 1 and 2. The return for a stationary vehicle is presented in Figure 1; Figure 2 shows the return for a vehicle approaching the radar at approximately 15 mph. The spectra of Figure 1 clearly show spurious Doppler components occurring at odd multiples of the polarization rotation rate of 500 Hz. Lower amplitude components also occur at multiples of the 40 Hz conical scan rate. These 40 Hz components were present in every case analyzed and varied with time and target situation. This variation indicates that in addition to the phase variations introduced by the conical scan motor, there is another contribution due to a random effect such as target misalignment.

Figure 2 shows that when the vehicle is moving, the spectrum due to polarization rotation is shifted upward in frequency by an amount corresponding to the target velocity. Fifteen mph corresponds to a Doppler frequency of approximately 400 Hz at our transmitted frequency. The 400 Hz Doppler component associated with target velocity is considerably larger than the spurious components which are present at about 900 and 1900 Hz due to polarization rotation. The relatively large spurious components probably indicate a larger polarization sensitive component that those assumed for aircraft type targets in the analytical investigations. Significant polarization sensitivity also was observed in the measured cross section of the vehicle; this cross section varied about 3 dB depending upon the transmitted polarization.

During the coming months, primary effort will be devoted to collection and analysis of field data. As soon as practicable, data from aircraft and

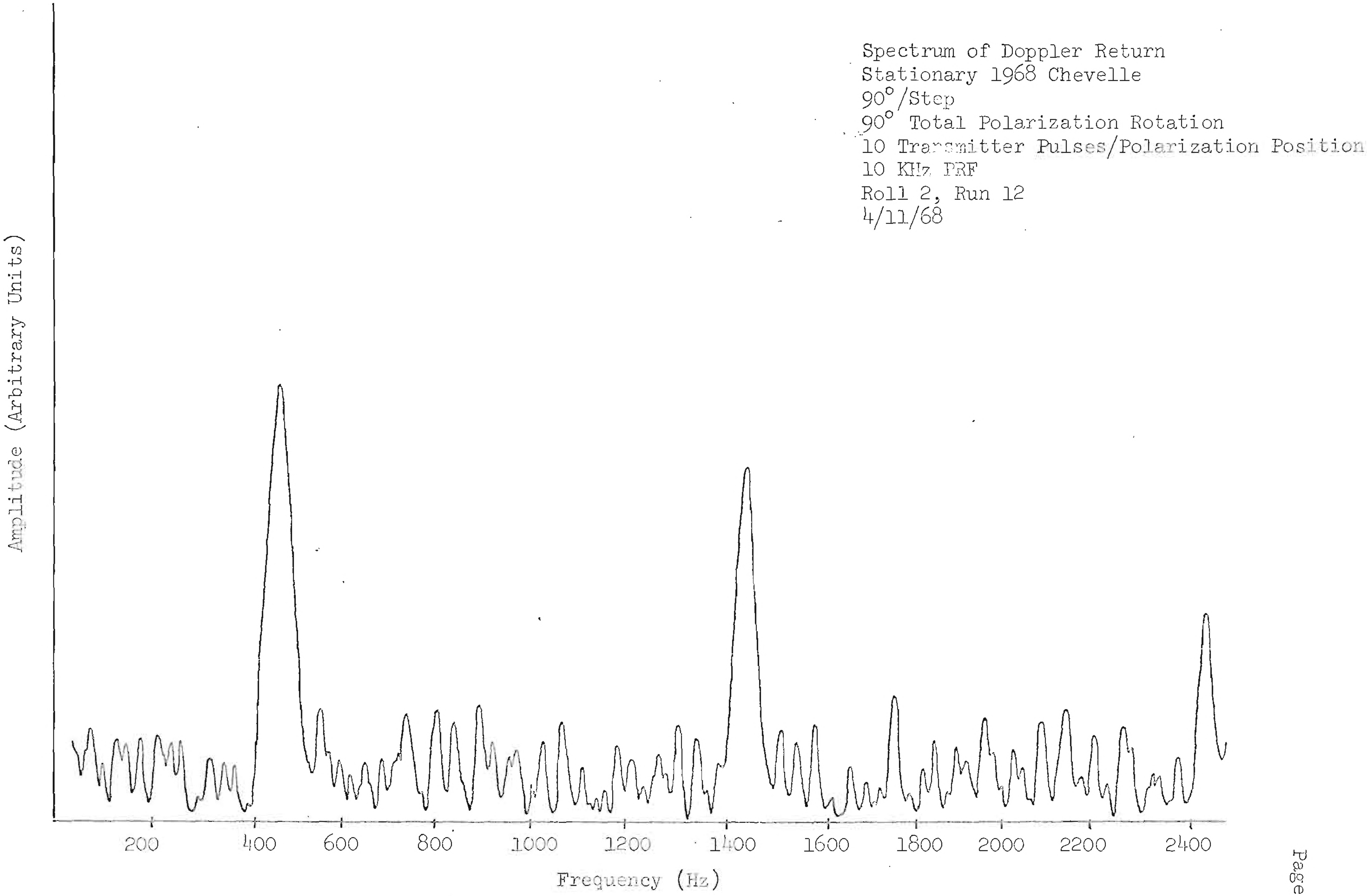
Spectrum of Doppler Return
Stationary 1968 Chevelle
90°/Step
90° Total Polarization Rotation
10 Transmitter Pulses/Polarization Position
10 KHz PRF
Roll 2, Run 12
4/11/68
Amplitude (Arbitrary Units)
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Frequency (Hz)

Figure 1

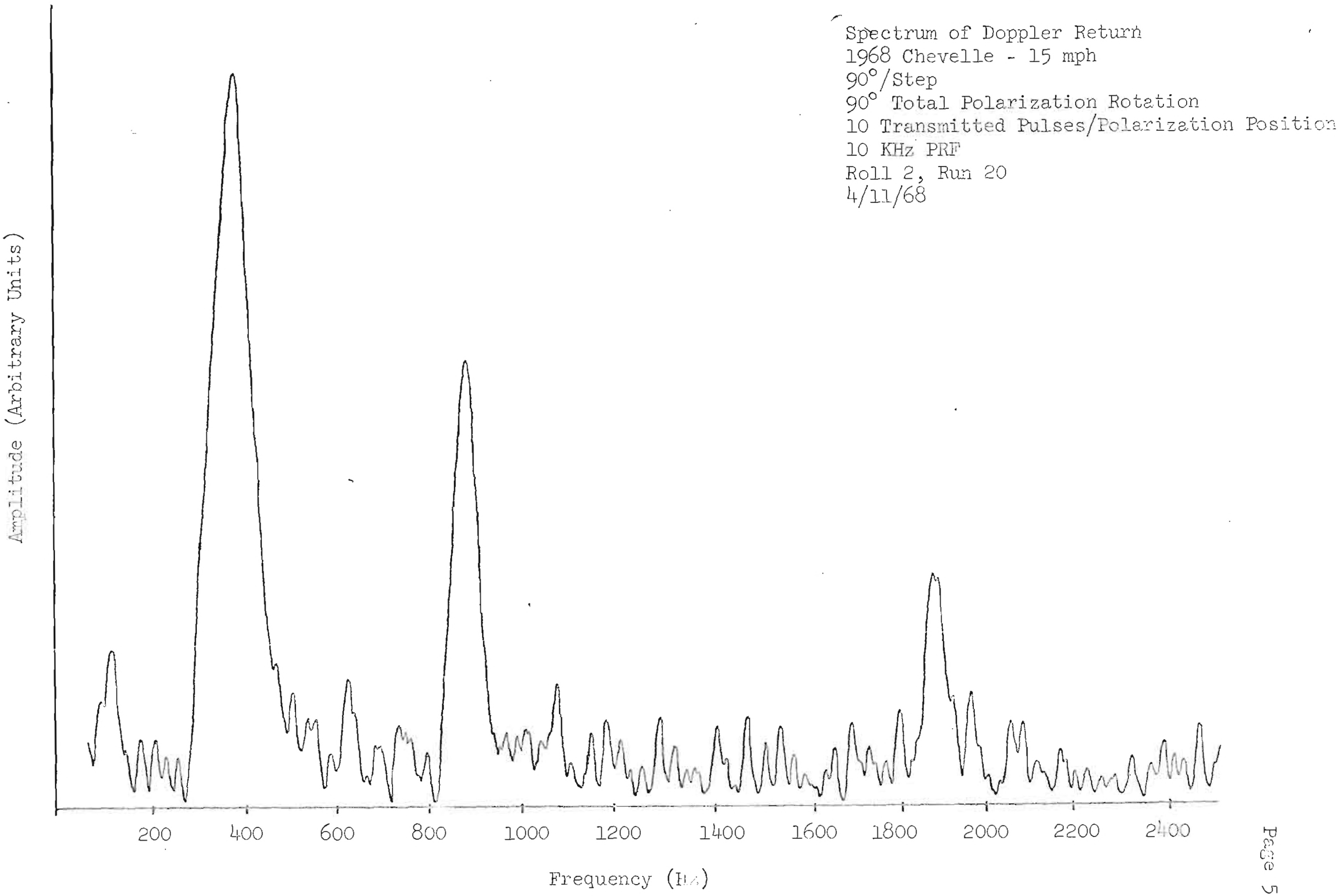
Spectrum of Doppler Return
1968 Chevelle - 15 mph
90°/Step
90° Total Polarization Rotation
10 Transmitted Pulses/Polarization Position
10 KHz PRF
Roll 2, Run 20
4/11/68
Amplitude (Arbitrary Units)
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Frequency (Hz)

Figure 2

tank type targets will be recorded. Additional analytical studies will be performed for any cases of particular interest and the study of the effects of polarization agility on range measurement accuracy will be intensified.

Respectfully submitted,

George W. Ewell
Project Director

GWE:na

Approved:

Marvin E. Wallace
Technical Coordinator

cc: R. C. Johnson
Head, Radar Branch

A-1034

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION

225 North Avenue, Northwest · Atlanta, Georgia 30332

17 June 1968

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U. S. Army Missile Command
Redstone Arsenal, Alabama 35804

Attention: AMSMI-RER

Reference: DA-AH01-67-C2322

Title: Polarization Agility Effects Study

Subject: Monthly Progress Report No. 11

Gentlemen:

A summary of progress for the period 1 May through 31 May is contained herein. During this period a field operation was conducted with a M-48 tank as the primary target, the radar return from the tank was analyzed in order to determine some of the effects of polarization agility on doppler information, and an investigation of the effects of polarization agility on the "range glint" of a two-scatterer target was performed.

On 21 May, Georgia Tech and MICOM personnel conducted a field operation which was designed to observe some of the effects of polarization agility on the radar return from a M-48 tank. The information of most interest was the doppler return, but some effects of polarization agility on radar tracking were also observed. The doppler information from stationay and moving targets was recorded for a wide variety of polarization rotation sequences. This recorded doppler information was returned to Georgia Tech where spectral analyses were performed to identify the principal doppler components which were present in the radar return.

The doppler spectra varied considerably depending upon the particular target situation. The doppler spectra generally exhibited a frequency component due to target velocity, surrounded by spurious components due to polarization rotation. All of the spectra which were investigated exhibited relatively small components occuring at multiples of the 40 Hz conical scan rate, and it has been shown experimentally that the amplitude of these components is related to small angular misalignments of the radar antennas and the radar target.

The doppler spectrum for several moving targets are presented in figures 1 through 3. Figure 1 is the doppler spectrum from a moving M-48 tank for a single polarization (vertical polarization), and indicates the appearance of the spectrum of the doppler return without polarization agility. Figure 2 illustrates the largest spurious responses due to polarization agility which were observed. The large component at approximately 500 Hz is due to target motion and is surrounded by spurious components separated from the "true" doppler component by multiples of the polarization rotation rate of 125 Hz. Spurious doppler components of this magnitude are not typical, and Figure 3 shows a case where there are no appreciable spurious components present which are due to polarization agility. The most common behavior lies somewhere between these two extremes, with the spurious responses having an amplitude of about one fourth of the component which would normally be associated with target velocity.

During this field operation two other effects of polarization agility were observed. While illuminating a corner reflector with a polarization rotation sequence of 5-5/8° per step, 180° total polarization rotation, 40 transmitted pulses per polarization position and 50 KHz PRF, an error signal voltage was produced by the radar which would ordinarily correspond to about a $\pm$ 3 mil error. The effect is because there is a small variation in antenna gain and target cross section with polarization, which produces amplitude fluctuations in the radar return which occur at the polarization rotation rate. This particular scan sequence yields a variation in amplitude of the target return which occurs at approximately the 40 Hz conical scan rate, and these variations are interpreted by the radar as amplitude variations due to a radar pointing error. This demonstrates the necessity for keeping the polarization rotation rate faster than the conical scan rate of a conical scan radar.

The radar was used to observe the M-48 tank when it was partially obscured by heavy ground clutter, primarily grass from two to three feet tall. The wind was blowing, and the resultant motion of the clutter introduced random variations of considerable amplitude into the radar error signals. It was observed that polarization agility considerably reduced these variations in the error signals of the radar, thus indicating that polarization agility may reduce tracking errors when attempting to follow targets in heavy ground clutter.

As part of this investigation to determine some effects of polarization agility on range information, the "range glint" of a two-scatterer target model was analyzed. The particular target which was assumed was the "wire plus sphere" target, with the target separation in range being approximately one half the range resolution of the radar. The exact value of range separation, or relative phase difference between target components, was one of the variables in the investigation. The radar cross section of the polarization sensitive target component was assumed to be one half the radar cross section of the polarization insensitive target component. The analysis was conducted for a split-gate range tracker, and there were considerable range glint effects. The range glint without polarization agility was two-thirds of the range separation of the two scatterers. If a polarization agility sequence is used which is rapid compared with the time constant of the range tracker, a considerable reduction in range glint may be achieved. This particular case which was analyzed was a polarization rotation sequence of $22\frac{1}{2}^{\circ}$ steps for a total polarization rotation of 180°, and this resulted in a reduction of range glint to approximately 50% of its value without polarization agility.

During the coming months, a field operation will be conducted with an aircraft as the primary target. The compilation and arrangement of materials for the final technical report on this project will begin so that it may be printed and distributed by the end of July.

Respectfully submitted,

George W. Ewell
Project Director

GWE:jan

Spectrum of Doppler Return
M-48 tank- approx 8 mph
Vertical Polarization
10 KHz PRF
Roll 3, Run 30
5/21/68

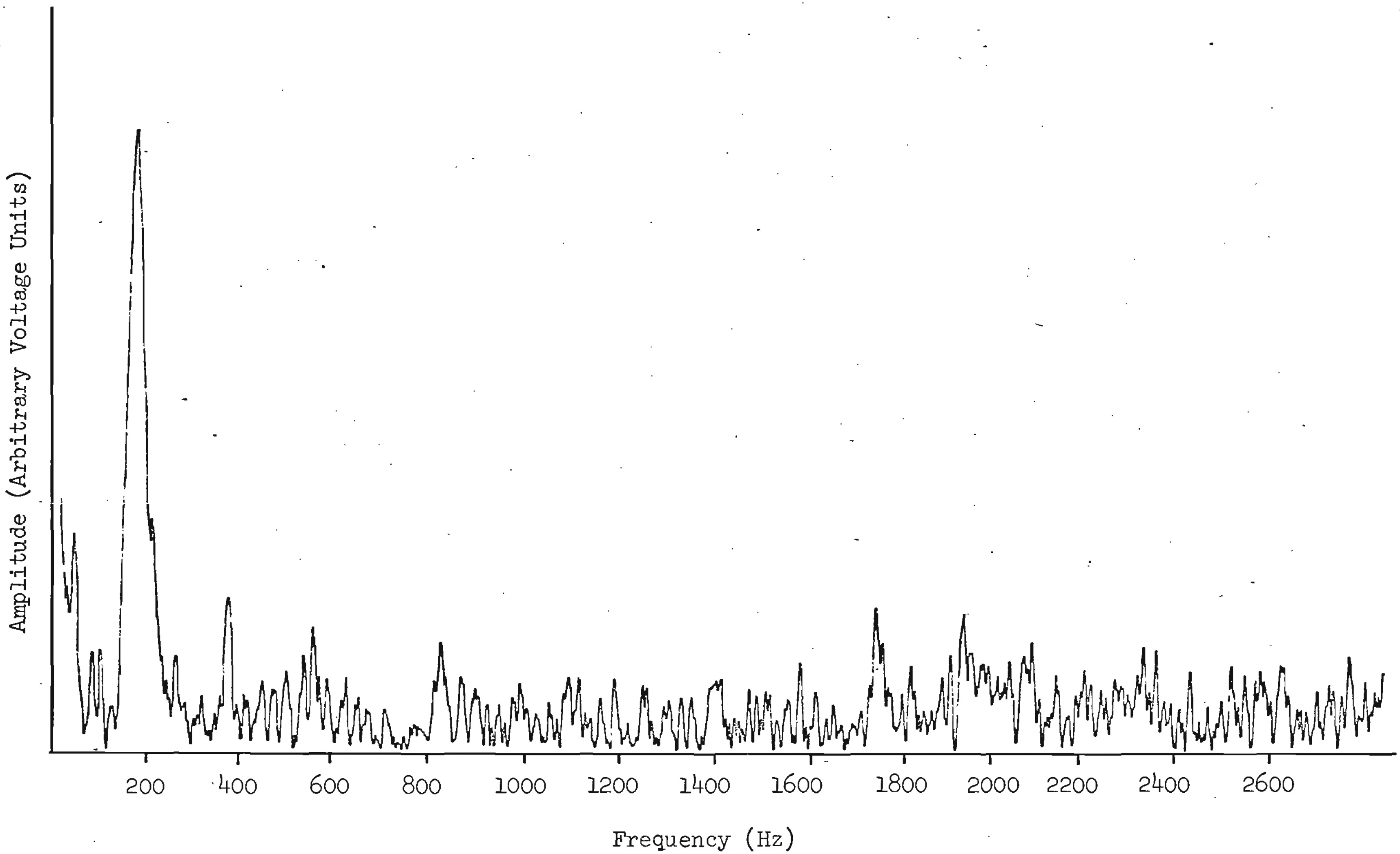

Figure 1

Spectrum of Doppler Return
M-48 tank- 18 mph
$22\frac{1}{2}^{\circ}$/step
180° Total Polarization Rotation
10 Transmitted Pulses/Polarization Position
10 KHz PRF
Roll 3, Run 36
5/21/68

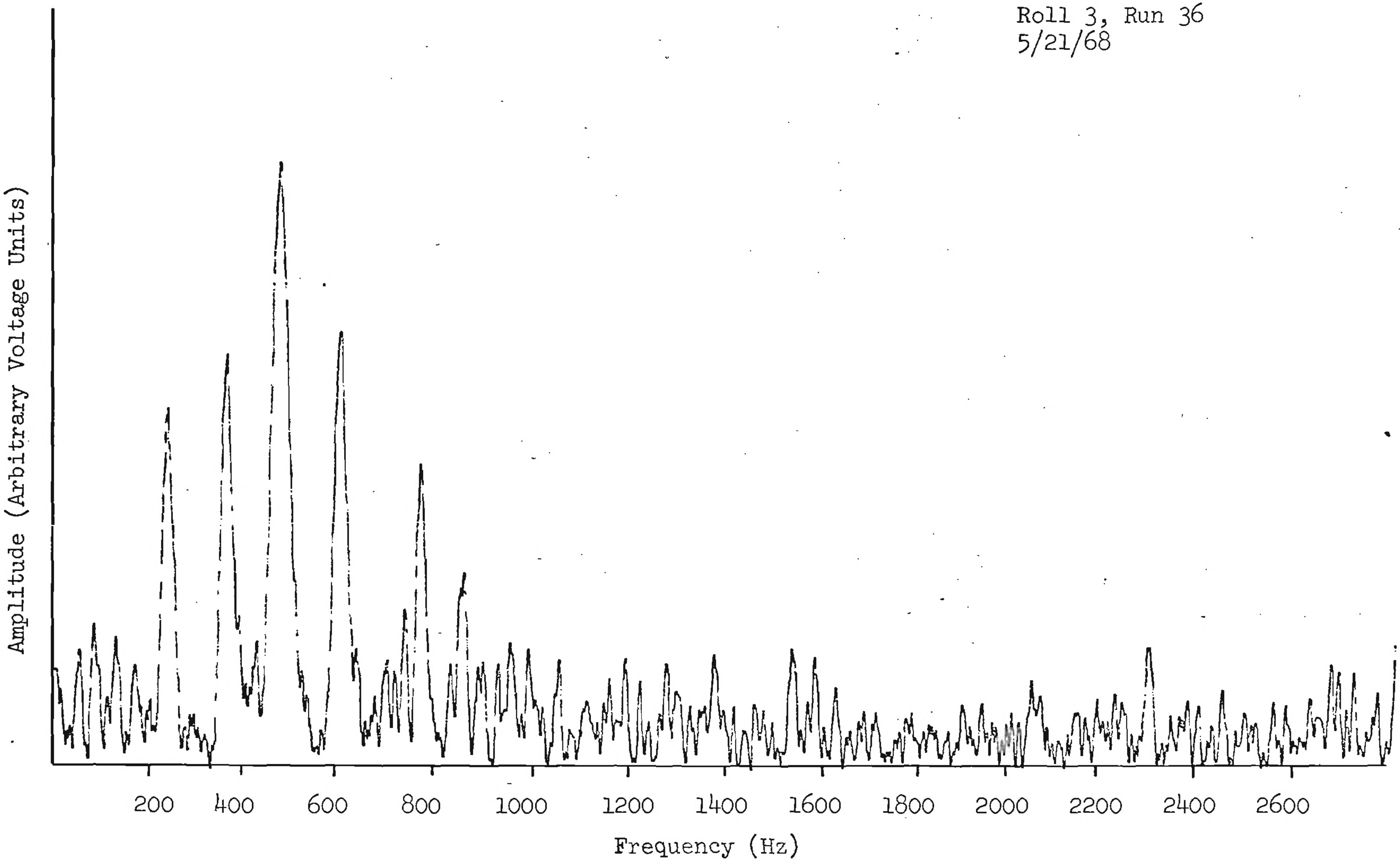

Figure 2

Spectrum of Doppler Retrun
M-48 tank- 18 mph
45°/step
180° Total Polarization Rotation
10 Transmitted Pulses/Polarization Position
10 KHz PRF
Roll 4, Run 3
5/21/68

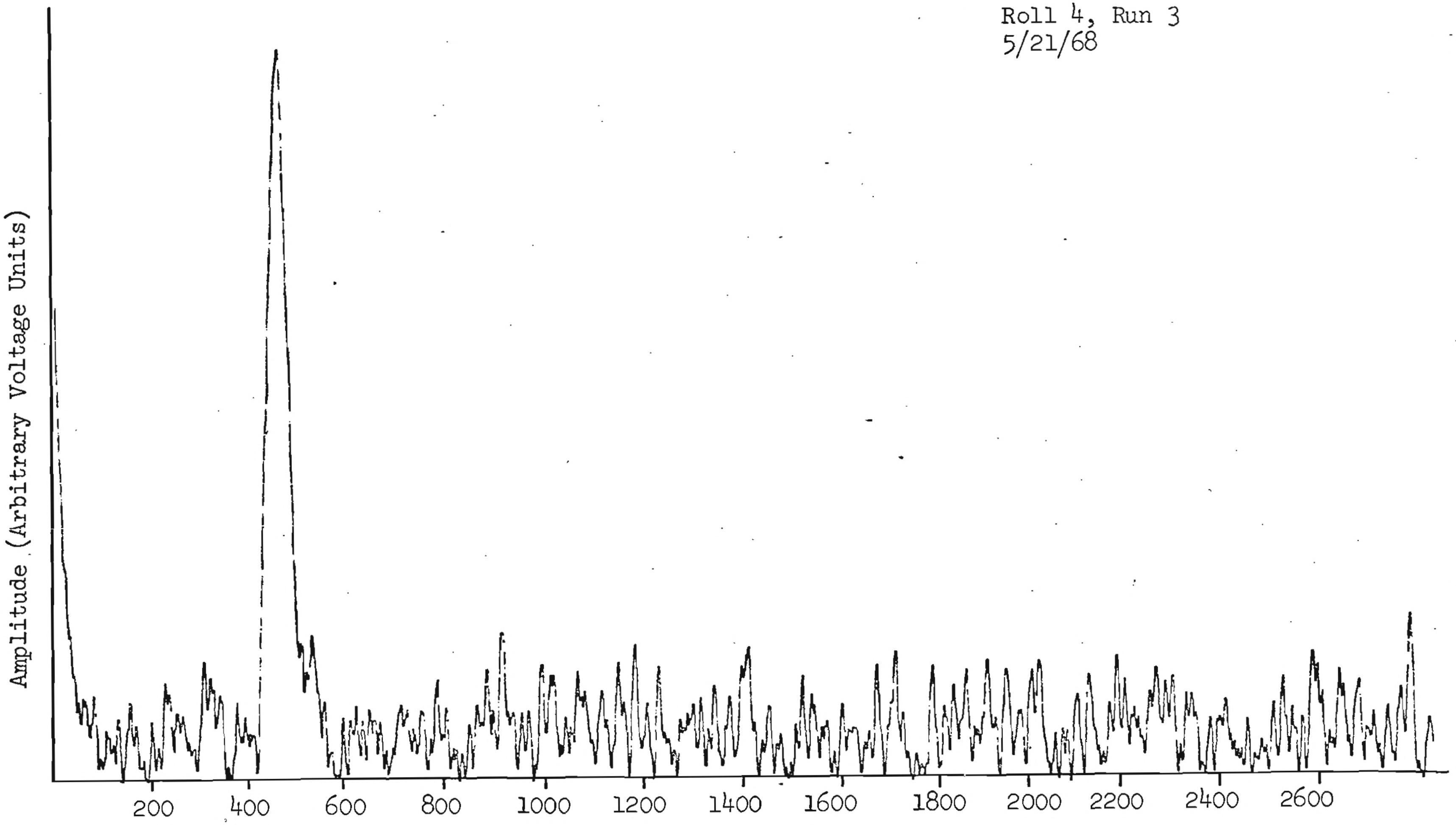

Figure 3